Electron Mediated/enhanced Ferromagnetism in a Hydrogen-annealed Mn:Ge Magnetic Semiconductor

Sunglae Cho*, Dang Duc Dung*, Won Seok Yun, Soon Cheol Hong,
Younghun Hwang and Wuwei Feng
Department of Physics, University of Ulsan, Ulsan 680-749, Republic of Korea
*E-mail: slcho@ulsan.ac.kr

A ferromagnetic semiconductor (FMS) is a material type that transplants the magnetic properties of ions into the host semiconductor material. They hold the promise of creating a new class of spintronic semiconductor devices using both electron spin and electron charge [1]. For the group IV-based Mn-doped Ge thin films, a Currie temperature (T_C) are 116 K and 285 K for the thin film and bulk, respectively [2, 3]. However, the origin of ferromagnetic in Mn-doped Ge still remains by difference event contrastive results in both experiment and theoretical by reported difference groups. Recently, Mn-doped Ge with H interstitials was predicted to be a ferromagnetic semiconductor with increased T_C and a magnetic moment comparable to the case without H-treatment [4]. In contradiction, Wang et al. predicted the reduction of T_C due to H impurities intending to bond to Mn ions in the Mn-doped Ge [5]. However, the role of *n*- and *p*-type carrier and carrier densities on the ferromagnetism in Mn:Ge is not clearly understood, even in H-treated Mn:Ge.

The $Mn_{0.09}Ge_{0.91}$ thin films were grown on semi-insulating GaAs(001) substrate by molecular beam epitaxy. The samples were annealed under pure H2 environment at various temperatures from 200℃ to 400℃. The annealing time were fixed one hour. The Hall measurement indicated that the carrier type changes of the *p*-type for as-grown Mn:Ge films to *n*-type for post-annealed samples in a hydrogen ambient. The results of SQUIDS measurement provided that hydrogen-annealed samples exhibit the increased T_C, from 165K to 198K, and the enhanced magnetic moment from 0.87 to 1.10 μ_B/Mn. The first principles calculation using the all-electron full-potential linearized augmented plane wave (FLAPW) method indicated that the addition of an electron carrier strengthens the ferromagnetic coupling between the Mn atoms, while the hole carrier caused it to weaken.

References

[1] S. A. Wolf *et al.*, Science **294**, 1488 (2001), and references therein.
[2] Y. D. Park *et al.*, Science **295**, 651 (2002).
[3] S. Cho *et al.*, Phys. Rev. B **66**, 033303 (2002).
[4] X. X. Yao *et al.*, New J. Phys. **10**, 055015 (2008).
[5] X. L. Wang *et al.*, Europhys. Lett. **87**, 47001 (2009)